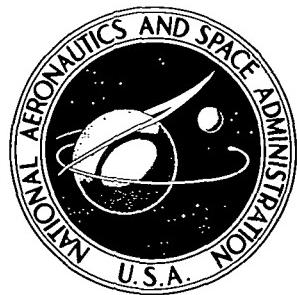


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FIRE SAFETY - A CASE STUDY
OF TECHNOLOGY TRANSFER

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16. Abstract This case study describes two basic ways in which NASA-generated technology is being used by the fire safety community. First, improved products and systems that embody NASA technical advances are entering the marketplace. Second, NASA test data and technical information related to fire safety are being used by persons concerned with reducing the hazards of fire through improved design information and standards. Transfer activities associated with these two types of technology utilization are strikingly different. The development of commercial fire safety products and systems typically requires adaptation and integration of aerospace technologies that may not have been originated for NASA fire safety applications. Commercial products, therefore, often bear little direct resemblance to their aerospace antecedents.			
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TABLE OF CONTENTS

Section	Page
INTRODUCTION	1
I. AN OVERVIEW OF THE FIRE SAFETY FIELD	3
II. NASA CONTRIBUTIONS TO THE DEVELOPMENT OF FIRE SAFETY PRODUCTS AND SYSTEMS	11
III. NASA CONTRIBUTIONS TO THE DEVELOPMENT OF FIRE SAFETY STANDARDS AND PROCEDURES	21
IV. A COMMENT ON TRANSFER ISSUES	31
REFERENCES	33

INTRODUCTION

The United States, the most technologically sophisticated nation in the world, has the highest death rate and the highest per capita loss from fire of all the industrialized nations. Each year nearly 12,000 persons die from fires in this country; each year 300,000 Americans are scarred or crippled by fires; each year more than eleven billion dollars are spent due to fires in the U.S. This document describes ways in which technology generated within the country's civilian aerospace program is being used to combat this scourge of fire. No attempt has been made to be exhaustive; nevertheless, the examples presented demonstrate the pervasive influence of the National Aeronautics and Space Administration's (NASA) contributions to fire safety and help to clarify the process by which aerospace technology is transferred to wider communities of interest. Section I presents an overview of the fire safety field. Sections II and III examine specific ways in which NASA-generated technology is being applied to help solve fire safety problems. Finally, Section IV focuses attention on technology transfer issues raised in preceding sections of this report.

SECTION I. AN OVERVIEW OF THE FIRE SAFETY FIELD

At approximately 6 p.m. on August 6, 1970, policemen and firemen began converging on the new glass and aluminum tower at One New York Plaza, where black smoke was billowing from the 33rd floor. Hundreds of spectators gathered in the street, cluttering the area and hampering rescue efforts. The fire blazing within the building was of such magnitude that a second alarm was turned in shortly before 6:30 p.m., and firemen were instructed to use gas masks to combat the heavy smoke. At 7:07 p.m. a third alarm was sounded, and around 9 p.m. more men and equipment were rushed to the scene. Two police helicopters flew over the building when it was reported that people were taking refuge on the roof. At 11:55 p.m. firemen reported the fire under control and, on the 50th floor, began a floor-by-floor search for victims.

The fire, involving the 32nd through 36th floors, had killed two men and injured 31 others, 24 of whom were firemen. Extinguishing the blaze required the services of at least 150 firemen, 25 pieces of firefighting equipment, and scores of policemen (Van Gelder, 1970).

To the consternation of the building and fire insurance industries, this fire again vividly demonstrated that modern buildings, constructed almost entirely from up-to-date, fire resistant materials, are still vulnerable to an old danger—fire. In fact, a theme running through the various reports prepared following the fire was “that while fire-resistant materials have made new buildings all but unburnable, furnishings and interior finishings work have made the interiors more flammable than they were 50 years ago” (Tomasson, 1973). Chief John T. O’Hagan of the New York City Fire Department observed, as his men were struggling to bring the fire under control, that “these new buildings may be fireproof but they are not that safe . . . But they keep building them because they’re inexpensive and look nice” (Fried, 1970).

Fire-Caused Deaths and Injuries

While dramatically illustrating the dangers of commonly used materials, the above example only begins to reveal the enormity of the fire problem in the United States. Every 12 seconds a destructive fire breaks out; every 2 minutes a house bursts into flames (WESRAC, 1971). In 1973 nearly 12,000 people died in fires; another 300,000 were injured, with many experiencing permanent physical and psychological scars. Yet, this carnage has brought no public outcry, as have other serious, less fatal, situations. For example, Figure 1-1 compares the numbers of deaths from fires in the United States with deaths of U.S. military personnel resulting from actions by hostile forces in Vietnam, for the period of 1961-1972.

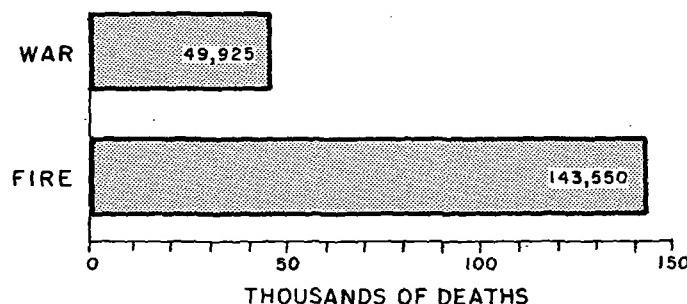


Figure 1-1. 1961-1972 Deaths: U.S. Fires Vs. Vietnam War. [Source: National Commission on Fire Prevention and Control, 1973.]

The United States, the most technologically sophisticated nation in the world, has recorded the highest death rate and the highest per capita loss from fire of all the industrialized nations. For example, reported deaths-per-million-population were 57.1 in 1973, almost twice that of second-ranking Canada (29.7); and, the economic cost of fires in terms of property loss, fire department operations, burn injury treatment, operating cost of the insurance industry, and productivity loss has been conservatively estimated to be more than \$11 billion annually (see Table 1-1).

TABLE 1-1. ESTIMATED ANNUAL U.S. FIRE COSTS*

SOURCE	COSTS (In Billions)
Property loss	\$ 2.7
Fire department operations	2.5
Burn injury treatment	1.0
Operating cost of insurance industry	1.9
Productivity loss	3.3
TOTAL	\$11.4

*Source: National Commission on Fire Prevention and Control, 1973.

Human Versus Technical Problems

Why such appalling statistics? The answer to this question is both simple and complex. There is an old saying in the fire protection field to the effect that fires have three causes: men, women and children. In most cases fires result from the careless or unwise action of human beings. Moreover, Americans are shockingly ignorant of basic fire safety knowledge. A nationwide survey of over 2,000 people of all ages revealed that almost no child under age seven knew that he should drop and roll if his clothing caught fire; fewer than 30 percent of the teenagers questioned knew that in the presence of smoke they should stoop low or crawl out of the fire area; very few families had a well-thought-out escape plan, including a predesignated meeting place outside the house (National Commission on Fire Prevention and Control, 1973). Much of the problem, from a layman's viewpoint, seems to reflect the attitude that "fire might be my neighbor's problem, but it isn't mine."

A far more complex set of issues, however, comprises the total picture. Fire safety also involves: fire departments, the clothing firemen wear and the type of equipment they use; the flammability of children's clothes; the use of realistic flammability tests for synthetic materials; the building codes that deal with architectural practices and the use of new types of textile fibers in carpeting and interior furnishings; the legislation needed to properly address the problem; the continuing research in areas such as combustion, fire retardant materials, and fire extinguishing techniques; and the means used to communicate "best practice" fire safety technology to specialists and the public.

Problems presently exist in all of these areas. Consider, for example, what is involved in introducing new technology into the nation's fire departments. Firefighters have a death and injury rate

higher than any other profession—15 percent higher than in mining, the next most hazardous job. It might appear obvious that innovations that reduce the hazards of fighting fires would diffuse rapidly throughout the profession; however, such has not been the case. In his article entitled "Fighting Fires: Only the Truck is New" (1973), Frohman has pointed out some of the barriers that must be overcome:

- Of the 25,000 fire departments across the country, only about 4,000 pay some or all of their firemen. Even among professional departments, there is rarely enough funding to hire specialists to evaluate new equipment.
- Improved products tend to be more expensive than their predecessors; in an era of shrinking budgets, fire departments are not looking for ways to spend more money.
- No generally accepted objective ways exist to measure the effectiveness of fire departments; thus, it is difficult to evaluate the contribution made by an improved piece of fire fighting equipment.
- The purchase of new equipment entails risk. Individuals advocating change often stand to lose more if new equipment fails to meet expectations than they will gain if it succeeds.
- Each department has its own unique procedures for purchasing equipment. This situation makes it difficult for manufacturers to project the demand for new products, thus the economics of mass production and product-line standardization are not easily achieved.

Another area of concern involves fire hazards associated with buildings. *America Burning*, the 1973 report of the National Commission on Fire Prevention and Control, stated that "as more and more Americans choose to live or work in high-rise buildings, their importance as a fire problem will increase. But high-rise buildings are not the only modern creation in which design impairs fire safety." A recent article in *Progressive Architecture* stated the issue even more bluntly.

The danger of fire should be a constant concern of architects and specifiers in designing a structure and in selecting its materials. There are rational methodologies for design and engineering of wind loads, earthquakes, and environmental factors. Fire safety has none (Rosen, 1974).

This indictment may seem overly harsh in light of the numerous building and fire codes that have been established to provide architects and planners with precisely the information needed to design fire safe buildings. Serious problems remain, however. For example, wide differences exist among the more than 14,000 building codes in the United States (National Commission on Fire Prevention and Control, 1973). Most codes place heavy emphasis on passive protection such as providing numerous exits, protecting structural elements, and retarding building-to-building fire spread. Almost none deals with building contents, such as upholstered furniture, draperies and carpeting that can create excessive fire loads. As was demonstrated in the case of the One New York Plaza fire, a fireproof structure can turn into an inferno if it contains flammable furnishings.

Equally important is a surprising lack of basic knowledge concerning the combustion behavior of furnishing materials during a fire. In May 1973, the Federal Trade Commission filed a complaint that the plastics industry and the American Society for Testing and Materials (ASTM) were misleading the public about the fire hazards of polyurethane and polystyrene and their copolymers. Building products

and furnishings were being described by the industry as "nonburning" and "self-extinguishing" on the basis of ASTM test methods that only provided data on the flammability of component materials, rather than finished goods. When incorporated into furnishings and tested under conditions more closely simulating a building fire, some of these materials presented a serious fire hazard (*Materials Engineering*, August 1973). ASTM is now reviewing all of its standards through a new Fire Hazards Committee (*Materials Engineering*, March 1974). Moreover, to minimize misunderstanding or misuse of ASTM tests, the Society has issued the following important caveat:

No ASTM method now extant should be used as a fire hazard standard as defined in the policy standard. Until the work of the new committee is completed concerning each ASTM method now extant, no ASTM method of test should be used for determining, evaluating, predicting or describing the burning characteristics of materials under actual fire conditions (Rosen, 1974).

Fire Safety Organizations

The existence of problems does not mean that there is a void of social and industrial concern over fire or that no progress is being made. Some 30 professional organizations are engaged in programs of fire safety education, establishment and maintenance of standards, and fire safety research. As already noted, ASTM is reviewing all of its test methods dealing with the effects of fire on materials. The tests include flammability characteristics, ease of ignition, rate of flame spread, and the surface burning characteristics and fire resistance of building materials. Underwriters Laboratory (UL) has been active in promulgating standards; each year, UL publishes the *Recognized Component Index* that classifies over 900 commercially available plastics in terms of comparative flammability characteristics. The International Association of Fire Fighters and the International Association of Fire Chiefs, the two most important professional organizations of the firefighting community, keep their members abreast of advances in equipment and firefighting technology. The influential 30,000-member National Fire Protection Association (NFPA) serves as an important clearinghouse for information on fires and fire safety. Through its numerous committees, NFPA develops and publishes advisory standards on virtually every aspect of fire protection and prevention. A particularly important NFPA publication is the *Life Safety Code*, designed to strengthen provisions for protecting the occupants of buildings rather than saving the building itself. This code covers construction, protection, and occupancy features relative to human safety. These standards, which are followed voluntarily, serve as the basis for legally enforceable standards in the form of state and local codes and federal regulations.

Federal Legislation

The federal government has become increasingly involved with fire safety. The Flammability Fabrics Act of 1953 charged the Secretary of Commerce with establishing standards for articles of wearing apparel and for fabrics used in wearing apparel. The Act was amended in 1967 to include the establishment of standards for interior furnishings and for fabrics and related materials used in interior furnishings. Enforcement of the standards was the responsibility of the Federal Trade Commission. The power to set and enforce flammability standards for fabrics now resides with the Consumer Product Safety Commission, created by Congress in 1972 to "conduct research studies and investigations on the safety of consumer products and on improving the safety of such products." Standards for children's sleepwear, rugs, small carpets, and mattresses have been promulgated; those for various other materials and consumer products are being developed.

Other federal initiatives have been taken to reduce fire hazards in places of employment. The Occupational Safety and Health Act of 1970, for example, provided a mechanism for establishing and

enforcing adequate fire safety standards in all places of work, and the Mine Safety Act of 1972 established stringent conditions for fire safety within mines, particularly coal mines.

The Fire Research and Safety Act of 1968 set up a program for fire safety research and education under the auspices of the National Bureau of Standards. The act also established a National Commission on Fire Prevention and Control to "...undertake a comprehensive study and investigation to determine practicable and effective measures for reducing the destructive effects of fire throughout the country." The Commission's report, *America Burning*, includes 90 specific recommendations that deal with all major aspects of fire problems.

These recommendations were the basis for the 1974 Federal Fire Prevention and Control Act, landmark legislation that established a coordinating agency—the National Fire Prevention and Control Agency—within the Department of Commerce. In addition to creating the new agency, the law:

- Provides for a National Academy for Fire Prevention and Control to advance professional development of fire service personnel;
- Requires the administrator of the new agency to develop a National Fire Data Center which would be a nerve center for a nationwide computerized system to collect, analyze, and disseminate information on prevention, occurrence, control, and results of all types of fires;
- Requires the administrator to develop, test, and evaluate fire equipment, including such specific items as clothing, breathing apparatus, fire detectors, and in-place fire prevention systems;
- Establishes within the Department of Commerce a Fire Research Center to perform and support research on all aspects of fire; and
- Authorizes the new agency to undertake programs to educate the public and to overcome public indifference concerning fire and fire prevention; a special target of these educational efforts will be the fires, such as building fires, in which human action or carelessness is a prime factor (U.S. Department of Commerce, 1974).

Federal Research and Development

Of the more than \$100 million spent annually on research related to fire, approximately 25 percent is provided by the federal government. Table 1-2 shows recent federal outlays and the span of research and development activities throughout the various federal agencies. It can be seen that the government supports programs which are directly related to meeting the needs of a particular agency as well as programs in basic and highly exploratory research.

TABLE 1-2. ESTIMATED FEDERAL FUNDING OF FIRE RESEARCH PROGRAMS*

SPONSOR	PROGRAM AREA	FUNDS (In Thousands)
Atomic Energy Commission	Nuclear plant fire protection	\$ 500
Agriculture	Forest fire prevention and control, fire weather modification	5,900
Commerce	Fabric and building fire safety, fire behavior, combustion	2,600
Defense	War and disaster-related fire and counter-measures, fuel materials, ammunition	3,600
Health, Education, and Welfare	Burn treatment, prevention and rehabilitation, epidemiology, surveillance	2,200
Housing and Urban Development	Urban building fire safety	700
Interior	Fire weather modification	4,700
National Aeronautics and Space Administration	Space systems fire protection	2,800
National Science Foundation	Fire behavior, materials flammability	2,200
Transportation	Aircraft inflight fire and crash fire protection, ship fire protection, railroad and hazardous materials fire safety, motor vehicle fire safety	1,300
U.S. Postal Service	Postal facility fire protection	100
TOTAL		\$26,600

*Source: National Commission on Fire Prevention and Control, 1973.

NASA's Research and Development Activities

NASA has conducted research and development in a broad range of areas related to fire safety. The following list briefly illustrates the types of research activities that have been carried out at the Agency's field centers in support of mission programs.

- Development and testing of fire resistant materials.
- Development of heat protective coatings.
- Development of high temperature lubricants and hydraulic fluids.

- Generation of data concerning the compatibility of materials with liquid oxygen and other highly reactive chemicals.
- Storage and handling of flammable and hazardous liquids and gases.
- Detection and extinguishment of hazardous fuel fires.

A partial listing of NASA Tech Briefs* relating to fire safety published during the past ten years (see Table 1-3) provides additional insight into NASA's extensive research and development activities in the field.

**TABLE 1-3. SELECTED TECH BRIEFS
RELATING TO FIRE SAFETY**

TECH BRIEF NUMBER	TECH BRIEF TITLE
FIRE RETARDANT MATERIALS	
65-10156	Inorganic Paint is Durable, Fireproof, Easy to Apply
68-10358	Fire Retardant Foams Developed to Suppress Fuel Fires
70-10450	Intumescent Coatings as Fire Retardants
72-10300	Polyimide Foams Provide Thermal Insulation and Fire Protection
73-10102	Nonflammable Potting-Encapsulating and Conformal Coating Compounds
FIRE PREVENTION TECHNIQUES	
68-10323	Hydrogen Safety Manual
70-10540	Chemical Treatment Makes Aromatic Polyamide Fabric Fireproof in Oxygen Atmosphere
72-10588	Technical Management Techniques for Identification and Control of Industrial Safety and Pollution Hazards
73-10235	Flammability Control for Electrical Cables and Connectors
FIRE DETECTION AND EXTINGUISHMENT METHODS	
67-10622	Fire Extinguisher Control System Provides Reliable Cold Weather Operation
69-10354	An Infrared Television System for Hydrogen Flame Detection
73-10128	Detector for Inspection of Fire Alarms
FIRE PROTECTION TECHNIQUES OR EQUIPMENT	
68-10277	Thermal Protective Visor for Entering High Temperature Areas
70-10318	Improved Heat Shield/Radiator
70-10544	Improved Heat-Resistant Garments
73-10369	Emergency-Escape Device
FIRE HAZARD TESTING OR EVALUATION TECHNIQUES	
68-10167	Evaluation of Ignition Mechanisms in Selected Nonmetallic Materials
70-10285	Investigation of the Reactivity of Organic Materials in Liquid Oxygen
70-10404	Detonation Hazards with "Safe" Industrial Solvents
73-10111	A Versatile Flammability Test Chamber

*One of the mechanisms used by the NASA Technology Utilization Office to acquaint industry and the public with the technical content of an innovation derived from the space program.

Conclusion

The immediate significance of federal and private investment in research and development related to fire safety is that it provides new capabilities in fire prevention, detection and control. In the longer term, it supports the formulation of laws and standards that provide the guidelines for designing a safer environment. Sections II and III examine ways in which knowledge generated through NASA's research and development activities is being used to find solutions to a wide range of fire safety problems.

**SECTION II. NASA CONTRIBUTIONS TO THE DEVELOPMENT
OF FIRE SAFETY PRODUCTS AND SYSTEMS**

Fire safety research has been conducted at NASA since the Agency's formation in 1958. The safe handling of explosively flammable fuels used in rockets, for example, has required that the Agency generate a large reservoir of data concerning the impact sensitivity and materials compatibility of these chemicals; design fire detection and extinguishment equipment for such fuels as hydrogen, which burns with an intensely hot but colorless flame; and develop procedures that provide the greatest measure of safety for personnel during a fueling operation. The tragic Apollo 204 fire of 1968 led to an intensive, successful effort to develop and adapt noncombustible materials suitable for the pure oxygen environments of manned spacecraft. The breadth of this materials development effort is illustrated in Table 2-1 which reviews selected high-temperature and flame-resistant materials used in manned spacecraft applications.

**TABLE 2-1. SELECTED HIGH-TEMPERATURE AND FLAME-RESISTANT
MATERIALS USED IN MANNED SPACECRAFT APPLICATIONS***

MATERIAL	APPLICATION EXAMPLES
TEXTILES	
Polybenzimidazole (PBI)	Harnesses, Tethers, Sleep Restraints, Containers, Thread
Teflon Fiber	Apollo Flight Coveralls, Abrasion-Resistant Patches for Space Suit
Asbestos Fiber (Asbeston)	Flame Barrier and Thermal Insulation
Nomex	Comfort Liner for Apollo Space Suit Thread, Outerlayer of Gemini Space Suit
Durette	Skylab Flight Coveralls
Beta Fiber	Outerlayer of Space Suit, Spacecraft Window Shades, Medical Kit, Towel Bags, Tissue Dispenser, Backpack Covers, Spacecraft Insulation, NASA Emblems, Mission Emblem, Flags, Astronaut Couch (Teflon Coated), Fire Protective Barriers
PLASTICS	
Polyimide	Adhesives, Food Boxes, Wire Insulation, Mechanical Shaver Cases, Flight Tape Recorder Cases
Epoxy	Adhesives, Potting Compounds, Fiberglass Laminate
Methyl Methacrylate (Plexiglass)	Dial Faces, Electroluminescent Panels
Polycarbonate	Space Suit Helmet, Dial Faces, Reaction Chamber for Crystal Growth Experiment, Mousehouse for Biostock Experiment
Polyvinylchloride	Wiring Insulation on Bio-Instrumentation
ELASTOMERS	
Silicone	Adhesives, Potting Compounds, Pads, Cushions
Fluorocarbon	Hose, Headrests, Flame Protective Surface Coating, Space Suit Boot Soles, Insulation Blanket
Urethane	Potting Compound, Conformal Coating, Sealants, Adhesives, Insulation
Polyacrylic Rubber	Liner in Fuel System
Polyisoprene	Bladder for Water Tank

*Source: Adapted from Johnston and Dawn, 1974.

NASA is providing information about these flame-resistant materials to other government agencies, industries, and organizations interested in fire safety. Indeed, some of these materials that were developed for the manned space program are finding commercial applications. The following examples illustrate the variety of ways in which technologies, developed for aerospace purposes, are adapted and applied in the development of nonaerospace fire safety products and systems: from the intact transfer of a nonflammable fabric to the complex integration of a number of technical innovations into an improved firefighter's breathing system.

Fire Resistant Products

NASA's demand for space cabin materials that neither support combustion nor generate smoke or toxic gases when heated in high oxygen environments has played a key role in the development of nonflammable foams, textiles, elastomers and coatings. Many of these materials are relatively expensive and provide a large degree of "overkill" with respect to existing nonflammability requirements; therefore, they rarely have been used outside of the space program. A few, however, have been successfully commercialized.

Nonflammable fabrics. A material known as Durette is one fabric that has been developed into a commercial product. Durette, a treated polyamide fabric that is nonflammable in pure oxygen, was developed by the Monsanto Company for the inside comfort clothing worn by crew members of Apollo and Skylab. The astronauts' garment and tote bags also were made from the fabric.

Monsanto is now marketing Durette for a variety of other uses. Hospitals in a number of major cities, including New York and Toronto, use the fabric for bedclothing and garments worn in oxygen tents or other oxygen-rich environments. The U.S. Navy has furnished its decompression chambers with Durette sheets and pillow cases, and Japanese steel mill workers wear protective clothing made from the fabric (Winslow, 1974). The material is relatively expensive, and commercial markets, while growing, are small compared to those for conventional textiles. In specialty applications where a combination of fire and high oxygen concentration creates an unusual hazard, Durette provides the needed protection.

Fire retardant coatings. In order to protect personnel and equipment during launch and reentry, NASA has developed highly efficient insulative coatings, some of which are now being used in other applications. The Avco Corporation in Wilmington, Massachusetts obtained a NASA license to produce intumescence coatings which were developed at the Ames Research Center. When heated, intumescence materials, by generating gases, expand into a tough insulative foam many times thicker than the original coating. The gases conduct heat away from a fire while the remaining foam forms a stable char which also reduces fire temperature. Although the primary application for the Avco material has been military aircraft, the company is adapting it for commercial markets. One of these new intumescence formulations is undergoing qualification testing by a major aircraft company for application on the inlet duct of the auxiliary power unit of wide-bodied commercial aircraft. Avco has also developed sheets of intumescence material which are used by a major hose manufacturer for wrapping inboard fuel lines on pleasure boats. Avco is also working with the Boating Industry Association and the U.S. Coast Guard to develop and test intumescence coatings to protect other vulnerable areas in boats, such as engine compartments and fuel tanks (Patterson, 1974 and 1975).

Another type of coating that has been used for inner heat shields on reentry vehicles since 1960 is now being used in the construction industry. In order to meet NASA specifications, the Emerson Electric Company, under contract to Johnson Space Center and Langley Research Center, improved its

patented material, which is based on the principle of sublimation cooling. Sublimation involves the transformation of a solid into a gas. Because this process absorbs large amounts of heat, it is an effective way to reduce temperature, prevent combustion and minimize thermal damage. The work for NASA provided the company with qualification data for coating variations to be used in different applications. In addition, NASA, as the first major customer, supported the company's development of a manufacturing capability for coating compositions.

In 1967 the Emerson employee who developed the material established his own company in St. Louis, Missouri, known as Thermo Systems, Incorporated, the name of which was later changed to TSI, Incorporated. The coatings were adapted to meet the requirements of commercial markets. TSI now markets coatings that utilize sublimation cooling, intumescence, and thermal reradiation for exceptional thermal protection. For example, a 0.200-inch coating will prevent a steel beam from overheating and collapsing during a two-hour fire. Although NASA still buys sublimation coatings, TSI's major sales are to the construction industry; these materials are being used increasingly in commercial and residential buildings to make structural steel fire resistant and to serve as fire retardant coatings for partitions, panelling, and furnishings (Feldman, 1974).

These cases illustrate different ways in which aerospace technology is transferred into the commercial sector. The case of Durette involves intact transfer, or that which occurs when a technical innovation developed to meet NASA's mission requirements is then marketed for similar applications outside of the aerospace program. Because NASA's needs rarely match those of the marketplace, such transfers are rare. While easy to identify, they represent only a small fraction of the technology that is commercialized. More typically, the NASA technology must be modified and integrated with other technology in order to produce a viable commercial product, as in the case of the fire retardant coatings. The following cases illustrate in a somewhat different manner this second type of transfer activity.

Electro-optical Imaging Equipment

Under contract to the Goddard Space Flight Center, the Santa Barbara Research Center, a subsidiary of Hughes Aircraft Company, has designed, developed, and fabricated many of the infrared electro-optical imaging systems used on NASA's earth observation satellites and interplanetary space probes. The company has used this expertise to design a portable infrared imager for the U.S. Army. This instrument served as the prototype for the Probeye infrared viewer, a compact, lightweight hand-held instrument based on the principle that all objects radiate infrared energy according to their temperatures. As the instrument scans a scene, it detects and converts the levels of such radiation to corresponding levels of visible light, producing on a small viewing screen a display of readily discernible temperature patterns for all objects within range. This capability permits firemen to locate people quickly and identify the source of fire in a smoke-filled room or building (Faith, 1974). Hughes is completing its first large production run of the Probeye instrument for commercial distribution in 1975 (Curry, 1974).

Through the experimental Four Cities Program in California, NASA assisted in introducing the Probeye instrument to urban applications. The Four Cities Program, funded jointly by NASA and the National Science Foundation, placed professionals from major aerospace companies in the cities of Anaheim, Fresno, Pasadena and San Jose. These professionals, backed by the technical resources of their companies, serve as science and technology advisors to city managers in order to facilitate the acquisition of technology that is relevant to urban problems. One of the problems put forward by the

Anaheim Fire Department was the need to clear heavy smoke from certain urban fire situations so that crews could find rescue victims and fire hot spots. This problem was defined technically as *viewing through the smoke* by means of a spectral "window" in the infrared. Further efforts by a technical team at Northrop, the participating aerospace company, uncovered several infrared viewing devices developed for the military. The lightest and smallest of these was Hughes' Probeye, then in advanced development as a commercial instrument (see Figure 2-1). Northrop contacted Hughes and arranged for a series of demonstrations which culminated in an evaluation program in May 1972. The program, which was a joint Anaheim/Hughes effort coordinated by the technical advisor, led to the purchase of a prototype which was subsequently replaced by a production instrument (Macomber and Wilson, 1974).



Figure 2-1. The Probeye Infrared Viewer.

Probeye has been used in numerous ways by various departments in Anaheim. It has provided the Fire Department with a quick method of locating hidden fires through walls, roofs, and ceiling panels and of verifying that all fires have been extinguished during mop-up operations. The Utilities Department has found it valuable as a quick means of checking power transformers for overheating and incipient breakdown, as well as for locating short circuits in buildings. It has been used to detect leaks in pipes concealed behind panelling in walls and ceiling structures. Search-and-rescue groups have used the instrument to locate people and vehicles. Public Technology, Incorporated, a nonprofit organization established in 1971 to assist state and local governments in using available technologies for their problems, is conducting demonstrations of the instrument around the country (Macomber and Wilson, 1974).

Remote Fire Hazard Sensor System

In some cases a synergistic combination of technologies is required to provide an effective solution to a problem. A good example of this type of transfer situation is illustrated by the California Division of Forestry's current evaluation of an automated data acquisition system. The division was seeking an improved way to acquire information on fire hazard parameters in brush-covered areas of the state. It had a number of remote sensing stations that measured air temperature, wind velocity and direction, and humidity. The accumulated data, which were collected manually, provided a periodically updated index on fire hazards in the vicinity of the station.

The Forestry Division asked the Ames Research Center for assistance in automating the data acquisition system by using a satellite relay station. The Electronics Development Group of Ames designed and constructed a prototype data collection platform that uses the transmission capabilities of the Earth Resources Technology Satellite (renamed LANDSAT) to relay data to a ground receiving station. Powered by a wind-driven generator, the unit can also transmit the data by telephone lines or by a microwave telemetry system. Data are printed out daily at Ames and delivered to the division. The sensing station has been in successful operation for eighteen months.

In 1975 a second station that will use both LANDSAT and the Geostationary Operational Environmental Satellite (GOES) will be added to provide the division with real-time data printed out in its Sacramento offices (Lum, 1974). Ames has also conducted a cost trade-off study that indicated satellite transmission will be the most cost-effective of any telemetry system for the remote stations, provided that the transmission channel can be shared by other users. It is estimated that fire losses could be reduced by one to five percent with the satellite telemetry system and that the system could be amortized in one to four years (Nishioka, 1974).

A staff meteorologist of the California Division of Forestry envisions a network of sensing stations around the state. Not only will the network provide data to determine fire hazard profiles, but it will also give real-time information to a dispatcher who can then allocate the division's men and equipment to those places exhibiting the greatest fire hazard potential (Innes, 1974).

The Firefighter's Breathing System

The NASA-funded development of an improved firefighter's breathing system illustrates both a complex type of technology transfer activity and how technology developed for one application can provide a technical nucleus for other applications. In addition, it demonstrates how NASA's Technology Utilization Office serves as a catalyst in developing public sector applications for aerospace technology. The firefighter's breathing system is currently in the final stages of field evaluation and should be commercially available by the fall of 1975.

NASA's development of a new breathing apparatus originated with the strongly expressed need by municipal fire departments for the improved equipment. Many firefighters neglect to use a breathing apparatus because conventional equipment tends to restrict a firefighter's mobility and vision. The result has been an unnecessarily high number of injuries due to smoke inhalation.

In cooperation with the National Bureau of Standards' (NBS) Fire Technology Division, Public Technology, Incorporated (PTI), the National Fire Protection Association, the International Association of Fire Fighters, and the International Association of Fire Chiefs, NASA initiated an effort in the spring of 1971 to develop improved equipment. PTI polled cities on their needs and

then organized a User Requirements Committee. The Committee included fire chiefs, city managers, and a representative of the NBS Fire Services Program. This group identified the deficiencies of available breathing systems: insufficient duration of air supply, excess weight and size, potentially dangerous protrusions, and lack of an adequate air-depletion alarm (NASA SP-5119, 1974).

Based on these results, the Technology Utilization Office funded the Crew Systems Division of the Johnson Space Center—the group responsible for space flight life support systems—to apply its background and expertise in developing a more efficient breathing apparatus that would also remain within the cost range acceptable to most fire departments. The selection of this group was particularly appropriate because, in a number of fundamental ways, a firefighter's breathing system parallels an astronaut's portable life support system. Both must meet the physical and psychological needs of an individual working in a hostile environment, have minimal weight, and function reliably (McLaughlan and Carson, 1974).

An extensive engineering analysis to determine an optimum system concept identified the two basic design features for an improved breathing system. First, it should be an open, rather than a closed, loop system. The open loop system, in which exhaled air is discharged to the surroundings through a check valve in the face mask, is the one most commonly used by fire departments today. It has a number of advantages over the closed loop system, where the user "rebreathes" his own breath after water vapor and carbon dioxide have been removed and oxygen replenished from a tank of compressed gas. The advantages of the open loop system include low cost, simple maintenance and recharge, use of air rather than pure oxygen, and a reliable shut down and restart capability. A major disadvantage, however, is weight. In order to obtain a full thirty minutes of working time, a fireman must carry at least 33 pounds of equipment on his back and chest. Therefore, the second basic feature of the improved system involves the weight problem. The analysis indicated that a lightweight pressure vessel with 4,000 pounds per square inch (psi) of air pressure, rather than the usual 2,200 psi, would bring about a significant reduction in weight while still affording the user at least 30 minutes of working time. Other recommendations from the analysis included changing the shoulder mounting of the device to a more comfortable hip mounting, improving the donning and doffing capability, and improving the overall system and component performance (McLaughlan and Carson, 1974). Based on these recommendations, the Technology Utilization Office funded the development of a prototype system.

The most important innovation in the improved system is the lightweight pressure vessel. A composite structure made of an aluminum liner and a glass filament overwrap was selected as the most suitable type of pressure vessel because of cost, durability and safety. Martin Marietta in Denver, Colorado and Structural Composites Industries in Azusa, California, two companies with considerable experience in manufacturing composites for aerospace applications, were awarded contracts by NASA to design and fabricate the pressure vessels in two sizes: 40 and 60 standard cubic feet capacities. Both vessel designs were interchangeable with the rest of the prototype system and exceeded all performance requirements during an extensive testing program which included pressure cycling, thermal cycling, high temperature exposure, and water exposure and impact resistance.

The composite vessels show promise in other applications as well. For example, Martin Marietta is currently negotiating to license its pressure vessel technology to a major manufacturer of underwater breathing equipment who would produce the vessel for the firefighter's breathing

system and explore the possibility of using the technology in scuba systems (Chandler, 1974). Also, Structural Composites Industries has been awarded a \$300,000 contract by the Boeing Company to develop and produce the pressure vessels for use in the emergency escape slide inflation system on the Boeing 747. The new vessels, which weigh 60 percent less than the type of pressure vessel currently used, will save a total of 200 pounds on each 747 (Boeing, 1975).

The Scott Aviation Division of A-T-O, Incorporated, in Lancaster, New York, a manufacturer of emergency breathing equipment, contracted with NASA to design and construct the overall system. The lightweight pressure vessel provided an incentive to lighten the overall system in other ways as well. A light, bubble-type face mask was used; it is easy to don and provides excellent visibility. A support harness was designed to distribute the load on the hips, thus eliminating chest- or side-mounted apparatus that could interfere with the wearer's movements. Tough, compact hosing connects the pressure vessel to the face mask, which contains a lightweight automatic device to warn users of impending air cylinder depletion. Personnel at Scott worked under the technical supervision of experts at Johnson Space Center throughout the design and development of the prototype breathing system. In addition, NASA helped Scott obtain special permits or approvals from: the Department of Transportation, so the pressure vessels can be shipped as normal commercial freight; the National Institute of Occupational Safety and Health (NIOSH), for the automatic warning device; and the Bureau of Explosives, for the safety relief devices on the high pressure system (Sullivan, 1974).

Table 2-1 shows how effective these innovations have been in producing a markedly improved system. Cost analysis to date indicates that the new firefighter's breathing system will cost only slightly more than the existing equipment if adequate demand exists (McLaughlan and Carson, 1974).

**TABLE 2-1. COMPARISON OF NASA-DEVELOPED VS.
EXISTING FIREFIGHTER'S BREATHING SYSTEMS†**

FEATURES	EXISTING SYSTEMS	NASA SYSTEM*	NASA SYSTEM*
Stored Gas Capacity (Standard Cubic Feet of Air)	45 scf	40 scf	60 scf
Operating Pressure (Pounds Per Square Inch)	2200 psi	4000 psi	4000 psi
NIOSH Approved Duration	30 min	30 min	45 min
Total Charged Weight (pounds)	33 lbs	20 lbs	26 lbs
Cylinder Dimensions (inches)	6.8 in. Diam x 19.5 in. Long	5.6 in. Diam x 18.6 in. Long	6.5 in. Diam x 19.7 in. Long

* Design Improvements: Reduced weight/increased duration, simplified harness with weight carried on hips, reduced breathing resistance, improved regulator configuration, improved mask harness, and reduced mask leakage.

† Source: McLaughlan and Carson, 1974 and McLaughlan, 1975.

Field evaluations of the new breathing system are now taking place in Los Angeles, Houston and New York City. As part of these evaluations, firefighters are using the system as the normal protective breathing apparatus in various firefighting activities, with over two hundred successful fire ground uses having occurred. Reports indicate that firefighters are pleased with the reduction in weight and bulk, the ease of donning, and the overall comfort of the units (Anuskiewicz, 1975).

Scott Aviation is creating a manufacturing capacity to produce the NASA-developed firefighter's breathing system. The unit will be similar to the lighter prototype, with minor changes and refinements resulting from the field trials. The company plans to have units commercially available by the fall of 1975 (Sullivan, 1974). Figure 2-2 shows two of the systems being worn by firemen.



Figure 2-2. Firemen Wearing the New Breathing System.

Conclusion

Part of NASA's legal mandate in the Space Act of 1958 is to "provide for the widest practicable and appropriate dissemination of information concerning its activities." The need for active participation in the transfer of mission-oriented technology has been underscored in recent reports by the U.S. Comptroller General (1973) and the National Academy of Engineering (1974). Both reports concluded that more social value could be achieved from mission-oriented research and development if each federal agency would take an active role in adapting its technology for secondary applications. NASA's participation in the development of the fire safety products and systems reviewed in this section illustrates, in part, how the Agency has responded to this challenge: (a) by defining and characterizing a genuine need; (b) by using a systems approach in developing a solution; (c) by obtaining user inputs at all program development stages; and (d) by working actively with companies interested in producing commercial fire safety products and services.

In summary, aerospace technology and the technical capabilities of NASA were crucial elements in the design, development, and testing of new products and systems that improve fire safety. It must be recognized, however, that final transfer decisions are not made by the Agency—but by the potential user community. With the firefighter's breathing system, for example, the user community includes both the manufacturer applying the technology and the fire departments evaluating the new product. By understanding this dimension of the total transfer process and by designing an approach that deals with it directly, the NASA Technology Utilization Office established a transfer situation that is conducive to widespread acceptance of an important new system.

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SECTION III. NASA CONTRIBUTIONS TO THE DEVELOPMENT OF FIRE SAFETY STANDARDS AND PROCEDURES

New products and systems are not the limit of NASA's contributions to fire safety technology. NASA-generated data on the burn rate and combustion temperature of materials, for example, can be used to develop improved fire safety codes or to design a more fire retardant product.

This section examines two ways in which NASA is aiding the fire safety community in designing a safer environment: by conducting tests that generate data needed by planners and designers to reduce the hazard of fire, be it in an aircraft or in a high-rise building, and by compiling and integrating fire safety information to assist those who must handle flammable materials or deal with hazardous situations. The following transfer examples illustrate how NASA-generated data and information related to fire safety are contributing to the development of improved codes, standards and emergency procedures.

Tank Car Flammability Tests

Through an interagency agreement, the Federal Railroad Administration and NASA are cooperating in a program to reduce the hazards associated with transporting flammable liquids in railroad tank cars. The Ames Research Center is conducting laboratory tests and computer simulations of tank car fires to obtain data on prevalent fire environments that occur in rail-related accidents. As part of this program, a one-fifth scale tank car test has been carried out to provide temperature and heat flux data for a realistic fire situation, and many fire resistant coatings have been evaluated for potential applications on tank cars (Mansfield, 1973). The research is providing design information for more effective methods of protecting tank cars from fire in the event of derailment (Kourtides, 1975).

Aircraft Fire Technology Programs

As part of a comprehensive fire technology program, four NASA field centers and the Federal Aviation Administration are participating in a cooperative effort to improve the fire safety of commercial aircraft. These efforts include: a program at the Jet Propulsion Laboratory to develop additives which will lower jet fuel fire propagation rates and ignitability by reducing misting characteristics; work on fuel safety and a clearinghouse for aircraft fire safety data at the Lewis Research Center; and programs at Ames Research Center and Johnson Space Center to develop and test materials which will provide better protection from fire throughout aircraft.

This activity at Ames, for example, includes the development of a fire resistant, transparent plastic which can be used for aircraft windows. Rather than melting, as do conventional windows, this new material forms a tough, stable char that reduces the likelihood of an external fire entering the aircraft interior.

Low smoke producing, fire resistant polymeric materials for use in aircraft interiors have also been developed by Ames scientists. Under NASA support, major aircraft companies, such as the Boeing Company in Seattle, Washington, will be conducting full-scale flammability tests of these materials for applications in those parts of the aircraft where fires tend to start and go unnoticed, such as lavatories and cargo compartments (Kourtides, 1974). The first tests will use conventional materials to obtain baseline data on variables such as heat flux, smoke density, toxic gas concentrations, and patterns of smoke movement, with subsequent tests involving the advanced materials developed at Ames, as well as

other flame resistant materials (Vessel, 1975). In addition, another polymeric material, a foam for use as fuselage insulation to protect passengers even in the event of a fuel fire, is being developed at the center.

The Flammability Research Center at the University of Utah is also being funded by Ames to analyze the chemical composition and toxicological properties of the products of combustion from aircraft cabin materials. Again, conventional materials are being examined first. Results have already shown that some of the decorative film materials now used in aircraft can decompose into highly toxic, gaseous products (Futrell, 1974).

The Johnson Space Center, in addition to supporting an extensive program of developing improved aircraft furnishing materials, is conducting full-scale tests of commercial aircraft cabin materials and furnishings. Figure 3-1 shows a diagram of the Boeing 737 fuselage donated by United Airlines for these tests.

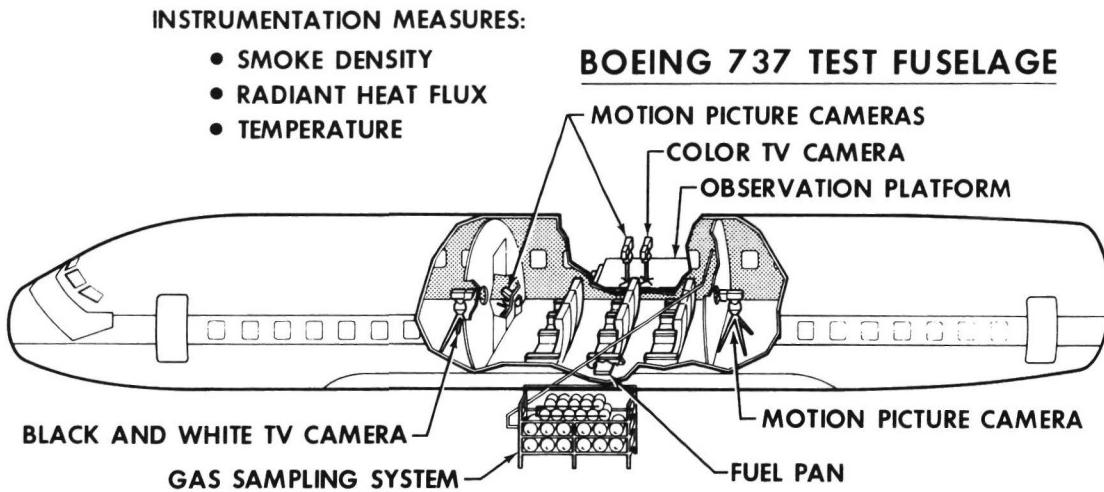


Figure 3-1. Fuselage Used in Aircraft Flammability Tests.

In addition to the instrumentation noted in the figure, the fuselage has two separate systems to collect gas samples every 30 seconds. All test data are recorded on magnetic tape and subsequently plotted in engineering units by a computer.

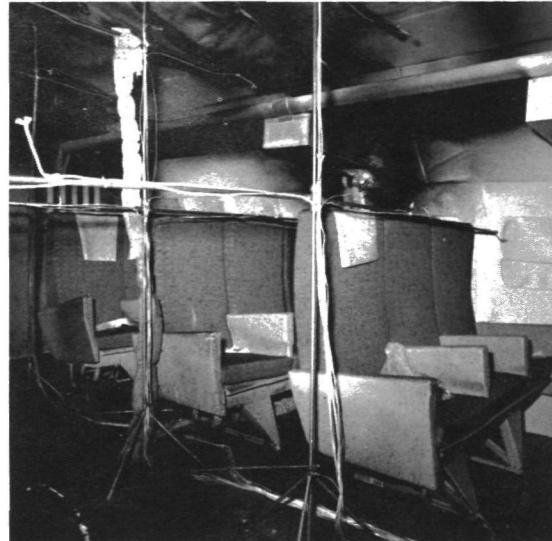
The testing program is designed to obtain data related to the following objectives: (1) defining the degree of propagation and the magnitude of fires resulting from a fuel ignition source within the cabin; (2) identifying the gaseous combustion products resulting from the ignition; and (3) determining the loss of visibility caused by smoke within the cabin.

Three full-scale tests have been completed. The first test used materials developed prior to 1968 both to compare the results with data obtained in similar tests conducted by the Aerospace Industries Association in 1967 and to provide a baseline for subsequent tests. The second test used newer, improved materials that offered the promise of improved fire safety. The third test was essentially a duplicate of the second, but it employed a smokeless fuel.

Persons observing the tests at Johnson included not only representatives of the Federal Aviation Administration and the aircraft industry but, also, members of firms that manufacture fire retardant materials (Stuckey, Supkis and Price, 1974). Figure 3-2, showing some of the test results, clearly indicates the superior properties of the newer materials tested.



A. Pre-1968 Materials



B. Improved Materials

Figure 3-2. Aftermath of Aircraft Fire Tests.

The significance of these testing programs goes far beyond the visible evidence that furnishings made of aerospace materials pose less of a fire hazard. The more fundamental question of how much more protection is actually possible from these materials can be answered by examining the data on heat flux, smoke concentrations, rate of flame spread, and rate of buildup to toxic gases. The Federal Aviation Administration (FAA) uses this NASA test data to help define practical fire safety standards for aircraft furnishings (McGuire, 1974). Smoke data, for example, is now particularly important to aircraft manufacturers because of a rule recently proposed by the FAA concerning the allowable levels of smoke generated by aircraft cabin materials (Vessel, 1975).

Test data are also being used by firms that produce materials for aircraft applications. The Mobay Chemical Company, for example, a major manufacturer of chemicals used in the production of polyurethane foams, has an active program to develop foams with improved fire resistance. Some of the company's new product prototypes were evaluated in the Johnson test program. The test results provided valuable input to Mobay's efforts to define the flammability characteristics of these prototypes and to indicate directions for further research (Darr, 1975).

These examples illustrate how NASA-generated fire test data are being used to develop safer aircraft. Next, a fire test project that NASA funded in order to obtain realistic flammability data for home furnishings is described. These latter test data are now being used by a large segment of the fire safety community.

Full-Scale Flammability Tests of Bedroom Furnishings

A testing program involving the flammability of bedroom furnishings was carried out by the Battelle Columbus Laboratories in Columbus, Ohio, under contract to NASA's Technology Utilization Office. The purpose of the program was to analyze the fire resistant and fire retardant properties of aerospace materials under both burning and smoldering conditions and to evaluate the potential fire safety advantages of these materials for use in furnishings for public buildings and homes. Specifically, investigators were concerned with evaluating three primary factors affecting human survivability: (1) the rate of fire development, (2) the rate of accumulation of smoke as a factor in obscuring escape-route visibility, and (3) the extent and rate of buildup of toxic gases (Hillenbrand and Wray, 1974).

Four full-scale bedrooms, differing only in the materials used to furnish them, were constructed and burned to provide comparative data on the fire hazards produced. Photographs and films were taken during the course of the tests, and measurements were made of temperature, smoke density, ventilation rates, and toxic gases produced, including carbon monoxide, hydrogen chloride, hydrogen cyanide and hydrogen fluoride. The test results summarized below clearly demonstrate the need for improved materials and show the extent to which space age materials can help to reduce fire hazards.

- The typical room, furnished from conventional retail sources, ignited easily and burned so rapidly that the room was totally consumed in flames after four minutes. After eight minutes, when the fire was put out, the contents of the room were nearly destroyed.
- The improved room, furnished with the best commercially available materials, showed substantial progress over the typical room in that the fire spread more slowly; however, visibility was poor after three minutes, and the entire room was burning after 16 minutes. When the fire was extinguished after 29 minutes, the room furnishings were destroyed.
- The space-age room, completely furnished with state-of-the-art materials, many of which were developed for the space program, did not ignite under the usual conditions (i.e., a pound of newspapers in a wastebasket and another three pounds of paper spread casually on the bed and on a chair in one corner). The room began to burn when a much larger starter fire was ignited, involving newspapers and lumber piled on the floor. This time, the flames were confined to the area of the starter fire for several minutes before they gradually spread to the "chair corner." After 27 minutes, a larger fire flared up in the corner and the flames spread throughout the room. The fire was extinguished after 33 minutes.
- The mixed room, furnished with materials identical to the typical room except for the substitution of the bed from the space-age room, burned primarily in the area where ignition occurred. This test illustrated the improvement in control of fire spread that can be achieved by carefully placing fire resistant materials in important paths of fire development.

The test data revealed the extent to which conventional fire retardant furnishings can decompose into combustible and toxic vapors as a result of the heat from other burning items in the room. This "ensemble effect" demonstrates the need for integrated fire tests of real furnishings, rather than for tests of isolated materials (Hillenbrand and Wray, 1974). This result reemphasizes the problem described in Section I concerning the limitations of small-scale laboratory tests in predicting the actual fire hazards of materials that are ordinarily used in combination with other materials in homes and offices.

Several of the materials used in the space-age test room, while more expensive than conventional materials, are now commercially available. For example, Durette, the nonflammable fabric discussed in Section II, was used for the mattress and box spring covers and the blanket, pillow case, and sheets of the test bed; this material is currently used for similar applications in a few U.S. hospitals. Beta fiber, a fine glass fiber developed by Owens-Corning and first used extensively in the country's space program, was also used for the drapes in the test room; a small number of hospitals and nursing homes are now using similar drapes.

More than 100 fire safety officials and researchers from government and industry have requested copies of Battelle's report directly from NASA. The Agency has distributed both the report and a film of the Battelle tests to the international fire safety community. The *Journal of Fire and Flammability*, which has 4,000 subscribers, reprinted the entire report in its June 1974 supplement, *Consumer Product Flammability*; an abbreviated version of the report was published in the March 1974 *Fire Journal*, the monthly publication of the 29,000-member National Fire Protection Association.

More than 30 requesters of the report were interviewed to determine the different types of application activities. These applications were generally found to be in one of three categories: fire test development and analysis; insurance company services; and a systems approach to fire hazards.

A major use of the report is as a source of information for developing and analyzing flammability tests in government and industry fire safety research programs. Companies such as Monsanto, Mobay Chemical, Owens-Corning Fiberglas, as well as the U.S. Department of Agriculture's Forest Products Laboratory, have used the document in this manner (Farley, 1975; Darr, 1975; Fitch, 1974; and Eickner, 1974). A scientist in the National Bureau of Standards' Division of Fire Technology used the report data in developing a simplified model for estimating the quantity of gaseous combustion products during a fire; such models play an important role in determining the general fire hazard of a material. In addition, the chairman of the ASTM Committee E-39 on Fire Hazard Standards stated that the Battelle work was used by the committee in making recommendations concerning fire test procedures (Taylor, 1975).

Another type of application for the report involves several major insurance companies, including: Liberty Mutual (Jespersen, 1975); Factory Mutual Research Corporation, a subsidiary of the Factory Mutual Insurance System (Corce, 1975); and M & M Protection Consultants, the loss prevention department of Marsh & McLennan Insurance Brokers, an international broker whose clients include over one-half of the nation's 500 largest corporations (Kolstad, 1975). These companies, by distributing information from the report to field inspectors and clients, expect to reduce policyholder fire risks through integrated approaches to fire hazard problems.

The most common use of the report has been to obtain a better understanding of the overall fire hazards associated with different kinds of furnishing materials and what actually occurs when a room burns. The editor of the *Journal of Fire and Flammability* stated that there is still too little of this information available to decision makers in industry and government, and the study results help answer this need (Hilado, 1975). A significant impact of the report is due to the way in which it is being used by leaders in the firefighting community and by others who formulate fire standards for materials.

Fire departments in Columbus, Ohio and New York City, for example, have used the report to increase their knowledge and understanding of the overall fire hazards of various types of materials

(Fadley, 1975 and Ifshin, 1974). This information is improving firefighting operations, as well as enabling the departments to recommend safer furnishings for new structures.

In addition to those professional activities that have been previously mentioned, others in government and industry who have found the report to be valuable in their professional society activities serve on such key committees as: ASTM Committee D-13, Textile Materials (Golub, 1975); ASTM Committee E-5, Fire Tests of Materials and Construction (Fitch, 1974); ASTM Committee E-39, Fire Hazard Standards (Fitch, 1974; Hilado, 1975; Taylor, 1975); a plastics flammability standards committee of the Society of the Plastics Industry (Darr, 1975; Fitch, 1974); the National Materials Advisory Board of the National Academy of Sciences (Eickner, 1974; Hilado, 1975); and Commission W-14-CIB, an international group concerned with fire safety (Golub, 1975).

Computer Programs to Calculate Chemical Equilibria During Combustion

Computer software developed initially for aerospace purposes is being converted for use in the fire safety field. The use of a NASA-developed computer program to help solve problems relating to coal mine fire safety provides a good example of this important type of transfer activity.

Scientists at the Lewis Research Center developed a Chemical Equilibrium Calculation (CEC) program for calculation of thermodynamic data in order to model the rocket engine combustion process accurately. Through continual refinement and updating at Lewis, CEC has become one of the most versatile combustion modeling programs that is currently available.

The CEC program was obtained in 1967 by the Bureau of Mines' Pittsburgh Mining and Safety Research Center to calculate critical parameters for coal mine fires. When a research program to analyze coal mine fires and explosives was initiated at the Pittsburgh Center in response to the 1969 Mine Safety Act, CEC became a crucial research tool. It has been used on a regular basis since then to calculate flame temperatures, pressures, and combustion product compositions under simulated fire conditions. The program has provided estimates of temperatures, pressures, and toxic products during coal mine fire extinguishment with halocarbon extinguishers such as Halon 1301. The data developed by the Safety Research Center on basic parameters such as pressure, temperature, and detonation and flame propagation rate will be used by manufacturers to design improved fire detection and extinguishing equipment for coal mines (Perlee, 1973 and 1974).

Manuals on Handling Hazardous Materials

NASA-produced handbooks that summarize the state-of-the-art in specific fire safety areas have been highly effective transfer mechanisms, as is illustrated in the following cases.

A Special Publication entitled *Handling Hazardous Materials* (SP-5032) was published by NASA's Technology Utilization Office in 1965. It describes the hazards associated with highly reactive chemicals, such as hydrogen, fluorine and nitrogen tetroxide, that NASA has used as fuels and oxidizers; this handbook also contains procedures by which such materials have been handled and stored safely.

The broad applicability of this information is indicated by the daily use of the handbook by employees of the Shelby Mutual Insurance Company in Shelby, Ohio who are concerned with loss prevention. Information in the handbook helps company representatives assist clients, many of whom must handle hazardous materials, in identifying and correcting potentially dangerous conditions (Griffith, 1974).

Lewis Research Center's Advisory Panel on Experimental Fluids and Gases updated and expanded the information on hydrogen presented in SP-5032 and published the *Hydrogen Safety Manual* (NASA TM X-52454) in 1968. Hydrogen, both as a liquid and as a gas, is an indispensable component of rocket fuel and spacecraft energy cells. The presence of hydrogen, however, constitutes one of the greatest single fire hazards in the space program. This hazard is caused by the fact that the odorless gas is ten times more flammable than gasoline; in addition, hydrogen fires are colorless. The manual presents, in an integrated manner, the extensive safety procedures that were developed by NASA engineers for storing, handling and using hydrogen. It describes the characteristics and the nature of hydrogen, design principles for hydrogen systems, protection of personnel and equipment, and operating and emergency procedures. As an operating manual, it delineates the acceptable standards and practices for minimum safety requirements.

The Borg Instrument Division of the Bunker Ramo Corporation in Delavan, Wisconsin used the manual to cross-check company operating and handling procedures for hydrogen. The division, producers of automobile clocks, timing devices, and synchronous motors, employs hydrogen to anneal the magnetic cores which are components in its products. The correlation of company procedures in the handling of hydrogen with those in the manual provided the firm with a greater level of confidence in its handling of this explosive gas (Leyda, 1974). Similarly, engineers at the Mobil Research and Development Corporation in Paulsboro, New Jersey used the manual to verify operating and safety procedures in its laboratories, which contain an extensive high pressure hydrogen piping system (Clapper, 1974).

Emergency Procedures Guide for Hazardous Propellant Spills

The next transfer example shows how information compiled by NASA and others has been adapted and used as the basis for producing another handbook of general interest to the fire safety community.

The Joint Army-Navy-NASA-Air Force (JANNAF) Safety and Environmental Protection Working Group prepared a collection of Propellant Spill Cards describing emergency procedures to be taken by shippers and local fire and police departments when spills of toxic or volatile propellants occur. The cards included fire and health hazard information as well as the immediate steps to be taken in case of fire, spill or injury. At the time, however, information was not available concerning how large an area in the vicinity of the accident should be evacuated to protect people from excessive concentrations of airborne vapors or fragments from bursting railroad chemical tank cars. A scientist at the Aerospace Safety Research and Data Institute at Lewis Research Center developed a mathematical model that provides quantitative estimates of this important parameter. For volatile chemicals, he incorporated such factors as spill area, rate of evaporation, and toxic Threshold Limit Values (TLV) into a plume dispersion model based on neutral atmospheric conditions. This model was used to calculate the size of the area, downwind from the spill, that needed to be evacuated (Siewert, NASA TM X-68188, 1972). The evacuation radius necessary to minimize fatalities from exploding tank cars was determined by a statistical analysis of data relating to tank car pressure bursts collected between 1958 and 1971. The analysis indicated that a minimum radius of 2,000 feet is required to limit the statistical probability of fatality to one-in-100 such accidents (Siewert, NASA TM X-68277, 1972).

Subsequently, the Chemical Propulsion Information Agency of Johns Hopkins University in Silver Spring, Maryland, under contract to the U.S. Department of Transportation (DOT), used the Lewis model to calculate evacuation areas required for a broader range of chemicals than the propellant

materials considered by JANNAF. The resulting information was then incorporated into DOT's *Emergency Services Guide for Selected Hazardous Materials*, which describes emergency procedures for 30 hazardous chemicals. Figure 3-3 shows the two-page format used in the handbook—the left-hand page contains potential hazards information and recommendations, while the right-hand page indicates the size of the downwind evacuation area based on spill size of the particular chemical.

The importance of the right-hand page information is indicated in the following paragraph taken from the foreword of the guide:

We believe this is the first attempt to publish defined evacuation areas in a readily useable format in case of a bulk spill of certain hazardous chemicals . . . the availability of this information and its use could reduce the number of people exposed to danger and should serve as a guide to the emergency personnel to avoid over- or under-reacting to the threat resulting from the spillage of the hazardous materials (U.S. Department of Transportation, 1973).

The handbook has been extremely well received by fire and police departments throughout the country. First issued in December 1973, with a printing of 13,000 copies, it became so popular that a second printing of 80,000 copies was made four months later, and a third printing of about 100,000 copies is planned for the near future. An example of this popularity comes from the Denver Police Department, where the handbook has been used in training seminars as a supplement to a guide they themselves developed. Six hundred copies of the DOT document have been distributed to emergency personnel through these seminars; a member of the Department reported that he has a continuing need to distribute more copies when they become available (Barretson, 1975).

Controlling Liquified Natural Gas Hazards

The final case in this section illustrates, in yet another way, how NASA's Technology Utilization Office is helping to solve an important fire safety problem: namely, the storage and handling of explosively flammable liquified natural gas (LNG). LNG is being stored in ever-increasing quantities within metropolitan areas because of shortages in conventional means of supply.

The hazards of LNG were underscored in the tragic explosion and fire at a storage facility on Staten Island, New York in 1973. Forty people were killed while repairing an empty storage tank. In the aftermath of this disaster, the New York City Fire Commissioner asked NASA's Technology Utilization Office for assistance in preventing any recurrence of the event.

A Fire Department spokesman reported that existing guidelines for LNG facilities are not adequate to meet the requirements of urban areas such as New York City. A crucial aspect of the problem involves developing criteria and operational procedures for the siting, design, construction, and operation of each facility (Fishkin, 1975). In response to this need, projects related to LNG safety were initiated by the Technology Utilization Office at two NASA field centers.

Risk-management system. Engineers at the Kennedy Space Center are completing a prototype risk-management technique for use by the New York City Fire Department in monitoring liquified natural gas plant development and operations. Designed for widespread use in the assessment and minimization of risks at hazardous facilities, such as liquified natural gas plants, nuclear power plants, and naphtha plants, this technique is presented in the form of an instructional document to guide the user in operating the risk-management system. In addition, it will provide a means of identifying risks and developing risk analysis techniques, as well as providing a follow-up reporting system.

HYDROGEN CYANIDE

(FLAMMABLE GAS, POISON, EXTREMELY HAZARDOUS)

POTENTIAL HAZARDS

FIRE or EXPLOSION	May be ignited by heat, sparks, flames. Container may explode in heat of fire. Flammable vapors may spread away from spill. Gas explosion and poison hazard indoors, outdoors or in sewers.
HEALTH	Vapors non-irritating, deaden sense of smell. If inhaled may be fatal. Skin contact poisonous. Runoff may pollute water supply.

IMMEDIATE ACTION INFORMATION

KEEP UNNECESSARY PEOPLE AWAY. KEEP UPWIND. ISOLATE HAZARD AREA.
WEAR SELF CONTAINED BREATHING APPARATUS AND FULL PROTECTIVE CLOTHING.
EVACUATE ACCORDING TO TABLE OF DISTANCES.
ELIMINATE IGNITION SOURCES ACCORDING TO IGNITION CONTROL DISTANCES.

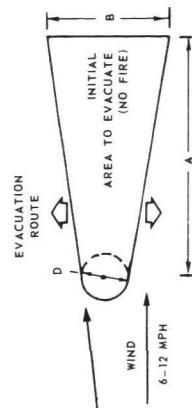
FIRE	<p>SMALL FIRES: Dry chemical or CO₂.</p> <p>LARGE FIRES: Water spray or fog.</p> <p>Let burn unless leak can be stopped immediately.</p> <p>Move containers from fire area if without risk. Stay away from ends of tanks.</p> <p>Cool containers with water from maximum distance until well after fire is out.</p> <p>Fight fire from maximum distance.</p>
SPILL OR LEAK	<p>No flares, smoking or flames in hazard area.</p> <p>Stop leak if without risk.</p> <p>Use water spray to reduce vapors.</p> <p>Do not touch spilled liquid.</p> <p>Isolate area until gas has dispersed.</p>
FIRST AID	<p>Remove to fresh air. Call physician.</p> <p>If not breathing give artificial respiration.</p> <p>If breathing is difficult give oxygen.</p> <p>In case of contact with material immediately flush skin or eyes with running water for at least 15 minutes.</p> <p>Remove contaminated clothing and shoes.</p> <p>Keep patient warm and quiet.</p> <p>Effects of contact or inhalation may be delayed.</p>

FOR ASSISTANCE CALL 800 424 9300

TABLE OF DISTANCES TO EVACUATE



(Based on TLV)			
Observed Sq. Ft. Area of the Spill	200	400	600
(A) Downwind, mi.	0.3	0.4	0.6
(B) Crosswind, mi.	0.2	0.3	0.3
(C) Circle, yd.	60	90	110
(D) Circle, yd.	130		



IGNITION CONTROL DISTANCES

Keep ignition sources and internal combustion engines at least 20 yards away from vapor cloud area.
Minimum evacuation radius from flying fragments from heated tank car or tank truck rupture should be 2000 ft. – greater, if possible. See Foreword.

WATER POLLUTION CONTROL

Prevent runoff of waste to a stream or body of drinking water and dikes for later disposal. The residue from a fire controlled with water and the water runoff are both very acidic and toxic.
Advise the EPA or the U. S. Coast Guard that a water incident is in progress.

Figure 3-3. Format of the *Emergency Services Guide for Selected Hazardous Materials* (showing emergency procedures to be taken for a bulk-spill of hydrogen cyanide gas).
[Source: U.S. Department of Transportation, 1973.]

Another portion of the Kennedy effort included a technical analysis of the New York City Fire Department's *Regulations for Manufacture, Storage, Transportation, Delivery and Processing of Liquified Gas*. This analysis led to recommended changes in the regulations. A report containing the revised regulations and the risk management methodology was issued in December 1974. The Fire Department is now in the process of incorporating these changes into its operating procedures (NASA SP-5120, 1975).

LNG safety manual. Since no useful compilation of LNG safety information presently exists, the Lewis Research Center has undertaken the development of a manual that will cover the operational hazards and safety procedures in the transportation, storage, and handling of liquified natural gas. Lewis engineers are utilizing the extensive data bank of the center's Aerospace Safety Research and Data Institute, which includes 6,500 documents on cryogenic fluids safety. Besides the handbook, Lewis will provide the Fire Department with a summary of abstracts and a bibliography of documents dealing with LNG safety (Orden, 1975).

Conclusion

The cases described in this section show the variety of ways in which test data, handbooks, and computer programs resulting from aerospace research are providing needed information and increased capabilities for the fire safety community.

SECTION IV. A COMMENT ON TRANSFER ISSUES

This case study has described two basic ways in which NASA-generated technology is being used by the fire safety community. First, improved products and systems that embody NASA technical advances are entering the marketplace. Second, NASA test data and technical information related to fire safety are being used by persons concerned with reducing the hazards of fire through improved design information and standards.

Transfer activities associated with these two types of technology utilization are strikingly different. The development of commercial fire safety products and systems typically require adaptation and integration of aerospace technologies that may not have been originated for NASA fire safety applications. Commercial products, therefore, often bear little direct resemblance to their aerospace antecedents.

NASA fire safety data and procedures, on the other hand, require little adaptation before they are applied to fire safety problems. In many cases, NASA has conducted or supported the application of aerospace expertise in developing better analyses of important fire safety problems that occur on earth. Such basic technical information can sometimes be more useful to nonaerospace engineers and planners than specific aerospace hardware.

Through both types of transfer activity, NASA technology is providing better solutions to the important problem of fire safety in America today.

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